HYBRID2 - A VERSATILE MODEL OF THE PERFORMANCE OF HYBRID POWER SYSTEMS

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ABSTRACT

In 1993, the National Renewable Laboratory assessed the available tools for predicting the long-term performance of hybrid power systems. No single tool was found to be capable of modeling the full range of hybrid power technologies being considered for the 1990s and beyond. As a result, NREL prepared a specification for a new model, called HYBRID2; model development by NREL and the University of Massachusetts began in 1994. HYBRID2 will have a user-friendly windows-based interface. A library of input data files will be provided with the model so that users can more readily model new applications by making incremental changes to existing project, power system, or component files. HYBRID2 will provide significant flexibility as to the configuration and dispatch (control) of the power system to be modeled. Both graphical and tabular output of results will be provided. The model is intended to provide comparisons of competing technology options on a level playing field. Initial testing of HYBRID2 is now underway.

INTRODUCTION

In 1993, the National Renewable Laboratory (NREL) made an assessment of the available tools from the United States and Europe for predicting the long-term performance of hybrid power systems. By hybrid power we mean combinations of two or more power sources - wind turbines, photovoltaics (PV), diesel gensets, or other generators - into integrated systems for electric power generation in remote locations. Our conclusion was that there was no single, user-friendly tool capable of modeling the full range of hybrid power technologies being considered for the 1990s and beyond. The existing tools were, in particular, lacking flexibility in system configuration and in dispatch of components. As a result, NREL developed a specification [Barley et al 1993] for a model, called HYBRID2, for making comparisons of competing technology options on a level playing field. This specification was prepared with a range of potential users in mind including not only the U.S. Department of Energy (DOE) renewable energy programs, but also the U.S. wind industry, technical consultants, international development institutions/banks, and rural electrification programs in developing countries.

During 1994, NREL and subcontractor, the University of Massachusetts (UMass), began development of HYBRID2 with funding from the DOE Wind Energy Program. It builds on the wind/diesel model, HYBRID1 [Manwell and McGowan, 1993], developed previously by UMass, and expands that model to accommodate the wider array of technologies used in hybrid power systems. This paper will provide an overview of the model's features, functions, and status.

FEATURES

From the beginning, one of our a primary goals was that HYBRID2 should be a user-friendly model. Several features of the model are aimed at achieving that goal:

- Windows-based Graphical User Interface (GUI) Specifically, the model is being programmed in Microsoft VisualBasic© (Professional Edition, Version 3). It will operate on PCs with at least a 386 processor and a DOS operating system. It will require a VGA video driver (640 x 480) or higher resolution.
- User-Specified Units The user will be able to make a choice of units within individual windows for entering data, either English or SI.
- Variable Levels of Input Detail This is an important feature in light of the fact that a typical simulation run with HYBRID2 could require 200 or more specific parameters as inputs. (An overview of the inputs and outputs of HYBRID2 are shown in Table 1 below.) First of all, default values for many parameters will be available at the click of a button. Second, the model will be distributed with a library of (1) typical village load data files, (2) wind and solar resource data files (representing a range of typical climatic conditions), (3) typical components specifications (such as gensets, wind turbines, PV modules, batteries), (4) example power systems, and (5) examples of complete projects. Our intent is to allow a new user to quickly model a new application by making incremental changes to existing data sets.

TABLE 1. OVERVIEW OF HYBRID2 INPUTS AND OUTPUTS

INPUTS	OUTPUTS
Loads: Primary, deferrable, and optional AC or DC connected or both	Energy Consumed/Delivered: Each component Each load For each time step
Site/Resource Parameters: Wind speed Incident solar Ambient temperature (optional) Elevation, latitude	Diesel Genset(s): Fuel consumption Run time v. loading # of starts
Power System: Configuration Component performance specifications Dispatch strategy	Battery State-of-Charge History Optimization (sizing): Wind capacity PV capacity Battery capacity Genset capacity
Economics: Component costs Fuel cost Financial parameters	Life Cycle Cost Analysis

- Help Features A "HELP" menu item will provide access to a complete glossary of terms.
- Output of Results HYBRID2 will have the capability to graph (both XY graphs and histograms) output parameters selected by the user. Selected summary data will be presented in histograms and pie charts in a pre-programmed format. Either summary or detailed tabulations of results will be accessible as well. HYBRID2 will also store ASCII files of output data for subsequent analysis at the user's discretion, say with a spreadsheet program.
- Economic Analysis An economic analysis capability will be provided with HYBRID2 including calculation of the simple payback period of the project; levelized annual maintenance, fuel, repair, and capital costs; life cycle cost, net present worth, and investment rate of return. In addition, the annual cash flow of a diesel-only system, or other "base case," will be calculated. Financial parameters that the user can specify will include taxes, equipment depreciation, equipment salvage value, operating and maintenance costs, repair/overhaul costs, fuel costs, discount, interest and general inflation rates as well as the selling prices of electricity for primary, deferred, and optional loads. Consideration will also be given to possible tax incentives and project loan grace periods.

- Optimization HYBRID2 will have the capability to calculate the optimum capacities of specific components in a power system for a given application. Initially, we will provide the capability to optimize the capacities of wind turbines, PV, batteries, and diesel gensets. This will be done by automating a process in which the model will step through a series of hypothetical systems and calculate a single economic figure of merit for each of them. That figure of merit will then be used to identify the optimum.

CONFIGURATIONS

The hardware configurations that HYBRID2 will model are shown in Figure 1. Each of the loads, components, or power conversion devices noted may be included in a power system simulation at the user's discretion. HYBRID2 will be applicable to power systems of a wide range of sizes - from stand-alone PV residential systems to multi-megawatt wind/diesel grids with multiple diesel gensets and multiple wind turbines.

- Loads The user will be able to select either AC-connected or DC-connected loads or both. The categories "Deferrable" and "Optional" will be provided to allow users to explore the value of load management methods. A "Deferrable" load is defined as one that can be deferred for either a fixed period of time or until renewable energy is available. An "Optional" load is one that has economic value but will be served only with surplus energy.
- Power Conversion The user will be able to choose from a range of power conversion devices between the AC and DC buses of a power system. These include both static converters (power electronics) and rotary converters. Various types of static inverters will be supported - unidirectional, bidirectional, and bimodal. Options for line-commutated or self-commutated inverter operation or both will be provided. This flexibility will allow HYBRID2 to effectively model series, switched, or parallel configured power systems [Nayar et al 1993].
- Components In designing HYBRID2, we have attempted to maximize flexibility and minimize limitations for the user in selecting components to include in a given power system. For instance, multiple wind turbines will be an option on one bus or on both buses. The user will be able to select multiple nonidentical diesel gensets, though these may be on only one bus at a time. At the user's discretion, the gensets may be capable of "back-drive" operation - absorbing power from the system. Like the gensets, a PV array will be allowed on only one of the two buses for a given simulation. Dump loads will be included to accommodate those systems in which "dumping" of excess power is required to control the AC frequency. Either lead acid or NiCad batteries will be the options for the DC storage component. We should note that if the power system being modeled has a DC bus (if any DC-connected loads or components are selected), the model will also require that a battery bank be defined for that system.

DISPATCH

The issue of dispatch of the components of a given hybrid power system becomes important for systems that have both diesel gensets and batteries. By dispatch, we mean the manner in which individual components are controlled so as to meet the load. To accurately simulate the performance of these systems, a model must address the following questions [Barley 1994]:

- How shall battery power be used to meet the load?
    - to meet transient peaks only, or
    - to meet all or part of the average load.
- When shall a diesel genset be started?
    - only when necessary to meet the load, or
    - also when needed to recharge the batteries.
- When running, how shall a diesel genset be loaded?
    - so that diesel use is minimized, or
    - always operated at full power (to the extent that all the energy may be used or stored).
- When shall a diesel genset that is running be shut off?
    - when the wind turbines, PV, and batteries can meet the load, or
    - when the wind turbines and PV can meet the load, or
    - when wind turbines and PV can meet the load as well as charge the batteries, or
    - when the batteries have been recharged to a specified state of charge.

Users of HYBRID2 will be asked to answer each of these questions for power systems that have both a diesel genset(s) and battery storage. The model will use these answers to guide the simulation logic that calculates dispatch of energy within each time step of a simulation. In this way, HYBRID2 will be able to accurately simulate the performance of all the system control strategies that we have encountered to date. Boost charge cycles for the battery will also be addressed.

SIMULATION METHOD

HYBRID2 will perform time series simulations of power system performance for time steps typically between 10 minutes to 1 hour. The model will use an energy balance approach within each time step such that the sum of the outputs of all the energy sources (such as gensets, wind, PV, and storage output) must equal the sum delivered to all the energy sinks (typically storage input, the load, and losses). A probabilistic method will be used within each time step to account for fluctuations in the renewable resources and in the load which can have a significant impact on performance. At the same time, the method is computationally efficient which helps to reduce model run time.

Within each time step of a simulation, system performance will be calculated by following the steps shown in Figure 2 [Barley 1994]. The "Net Load" (in box A) refers to all of the load(s) on the system less the contribution of the renewable energy sources. When this value is positive, it is the energy that must be supplied by the diesel genset(s) or battery storage or both. When the net load is negative, there is extra power available which may go to storage or to a deferrable or optional load.

The effect of the probabilistic method is that the net load is not a single value during a time step. Rather it is a distribution of values, and it is assumed that the values are normally distributed. In extreme cases, the net load may be positive for part of the time, but negative for the rest. The most significant aspects of the net load are its mean and its range (maximum and minimum values) which will affect the determination of which diesels are on line, how much power they produce, and how much fuel they use (Figure 2, boxes B and C). Next, the energy flow to or from the battery will be calculated (box D) and surplus energy will be made available to either deferrable or optional loads (box F). If the power system is incapable of meeting the load during a time step, the unserved load will be tabulated and reported. For power systems configured with fewer components or loads than in the discussion above, this process will be simplified.

GRAPHICAL USER INTERFACE

The graphical user interface (GUI) will be organized so that four key elements of a given project - an application of a hybrid power system - are readily accessible. These elements are:

- Loads
- Site and renewable resource characteristics
- Power system
- Economic parameters

The main window of the model (Figure 3a) will provide access to second-level windows in which each of these elements are defined. An example of a second-level window is the power system window (Figure 3b) which will show the power system configuration selected by the user as a simple electrical one-line schematic. Subsystem (Figure 3c) and component windows (Figure 3d) will also be provided for input/selection of additional power system detail. Input data will be aggregated and saved to disk files at three levels: by project, by power system, and by component. These files will be added to the library of files we will provide with HYBRID2 and can be accessed for later use. Development of this GUI is still underway, both the final layout and programming.

MODEL AVAILABILITY

NREL intends for HYBRID2 to be generally available in the public domain. Distribution will include both executable code and supporting manuals and will be done according to DOE guidelines for software distribution. We anticipate that the model will be released in the later half of 1995 contingent on a judgement as to its overall readiness. That judgement will be based on our own experience with the model and on the feedback from beta-testers outside of the development team.

Validations will also be used to test the readiness of the model. Many of the basic algorithms of HYBRID2, specifically those which were originally included in HYBRID1, have been validated in an extensive experimental program on the University of Massachusetts' Wind/Diesel System Test Bed [Manwell et al 1994, Baring-Gould 1995]. Furthermore, the data sets obtained during that test program are available and will be used for comparison against HYBRID2 simulations. We will also conduct validations against data sets from field installations as those become available.

We recognize that long-term technical support for HYBRID2 will be essential to its success. The extent and nature of that technical support will be based on identified need and on acceptance and use of the model outside of NREL. Long-term support will also be contingent on future DOE Wind Energy Program funding.

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